Geophysicists
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career of innovative contributions to geophysics through fluid mechanics.

In 1957, Phillips joined the Department of Mechanical Engineering at Johns Hopkins University. He returned briefly to the United Kingdom as assistant director of research in the Department of Applied Mathematics and Theoretical Physics at Cambridge, then came back to the United States permanently in 1963 as a full professor at Johns Hopkins, becoming a U.S. citizen shortly thereafter.

By the early 1960s it became evident that further progress on upper ocean dynamics required solving the thorny problems of nonlinear wave interaction and ocean mixing. Anticipating that these topics would have broad theoretical interest as well as many practical consequences in ocean science, Phillips began to collect material for a definitive book on ocean waves and turbulence. In 1965 his monograph *Dynamics of the Upper Ocean* was awarded the Adams Prize by the Royal Society of London. Upon its official publication a year later, it quickly became a fixture on desktops throughout the oceanographic world, was republished three times, and was translated into Russian and Chinese each twice. In 1968, Phillips was elected Fellow of the Royal Society at the age of 37. By way of decompressing after the publication of *Upper Ocean*, he published *The Heart of the Earth* in 1968, a highly original introduction to solid Earth geophysics intended for beginning scientists. Like *Upper Ocean*, *Heart* went through numerous reprintings in multiple languages and is unique in its emphasis on the scientific method as applied to geophysics—it clearly explains how geophysics is done, in addition to what is presently known about the Earth.

In addition to wave generation, the action of wind blowing over the ocean surface produces turbulence in a layer that grows with time as the result of entrainment mixing with the denser water below. In a famous laboratory experiment, H. Kato and Phillips measured the rate of entrainment in a stratified fluid as a function of the applied surface stress and derived the first scaling law for entrainment that was directly applicable to wind-induced mixing in the upper ocean, now understood to be a critical process for climate regulation (see *J. Fluid Mech.*, *37*(4), 643–655, 1969).

In 1967, Johns Hopkins formed the Department of Earth and Planetary Sciences by combining the former Geology Department with faculty from the Oceanography and Mechanics departments. Phillips became its first and longest-serving chair and its main visionary. Personal accolades during that period included the Sverdrup Gold Medal in 1974; president of the Maryland Academy of Sciences, 1979–1985; and Fellowship in the American Meteorological Society in 1980. As the second energy crisis hit the United States in the late 1970s, Phillips saw how cavalierly Americans were behaving toward an issue that directly affected their wallets and their security. In 1979 the Johns Hopkins University Press published his whimsically titled *Last Chance Energy Book*, a lively yet sobering account of the true costs and risks of energy policy negligence. It is now clear how far ahead of its time this book was.

The next chapter in Phillips's research began in the late 1980s, when he started collaborating with several Johns Hopkins geologists including Lawrence Hardie and John Ferry on the problem of how aqueous fluids infiltrate and react within permeable sedimentary and metamorphic rocks. This work culminated in 1991 in a Cambridge University Press monograph, *Flow and Reactions in Permeable Rocks*, and in 2009 in a second monograph on this subject, *Geological Fluid Dynamics: Sub-Surface Flow and Reactions*. More honors came during this period, including election to the U.S. National Academy of Engineering in 1996, Honorary Fellow of Trinity College in 1997, and finally, Fellow of AGU in 2006. In April 1998, hundreds of friends and colleagues packed Johns Hopkins's Shriver Auditorium to hear the world's most distinguished fluid dynamics experts from around the world pay tribute to Phillips on the occasion of his retirement from active teaching duties.

Phillips was much revered for his considerable diplomatic skills and rock solid integrity as well as his professional accomplishments. On several occasions, university presidents turned to him for leadership during times of crisis. Although he was fundamentally a private man, he possessed a gracious charm and a quick sense of humor. He had limited patience for trivial things but always seemed to have time for colleagues and students. He was a person one could talk with. Apart from his own research and teaching, Phillips drew his greatest pleasures from the simple rituals in his life: family; woodworking; skippering a small sailboat across the Quissett, Mass., harbor; or just chatting with a colleague in that familiar, hallmark pose—leaning back in his chair and quietly puffing his cigar. His departure marks the end of an era, and his presence will be sorely missed.

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Honors

Ralph Cicerone has been elected to a second 6-year term as president of the U.S. National Academy of Sciences beginning 1 July 2011. As president, Cicerone also serves as chair of the National Research Council, which conducts independent science, engineering, and health policy studies under a congressional charter.

The U.S. National Academy of Engineering (NAE) has elected 68 new members, including five AGU members: **Michael R. Hoffmann**, James Irvine Professor of Environmental Science, California Institute of Technology, Pasadena; former AGU president **John Orcutt**, professor of geophysics and Distinguished Researcher, San Diego Supercomputer Center, University of California, San Diego, La Jolla; **Karsten Pruess**, senior scientist, Earth Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, Calif.; **Ares J. Rosakis**, Theodore von Kármán Professor of Aeronautics and professor of mechanical engineering, and chair of the Division of Engineering and Applied Science at the California Institute of Technology; and **Mark D. Zoback**, Benjamin M. Page Professor of Geophysics, Stanford University, Stanford, Calif.

Steven Koch has been appointed the new director of the National Oceanic and Atmospheric Administration's (NOAA) National Severe Storms Laboratory in Norman, Okla. Koch, who begins his new assignment in April, has been director of the Global Systems Division at NOAA's Earth System Research Laboratory in Boulder, Colo. Prior to joining NOAA, Koch was an associate professor at North Carolina State University in Raleigh and a meteorologist at NASA Goddard Space Flight Center in Greenbelt, Md.

In Memoriam

Thomas J. Ahrens, 74, 24 November 2010, Fellow, Tectonophysics, 1959

Luis Gomberoff, 68, 13 September 2010, Space Physics and Aeronomy, 1993

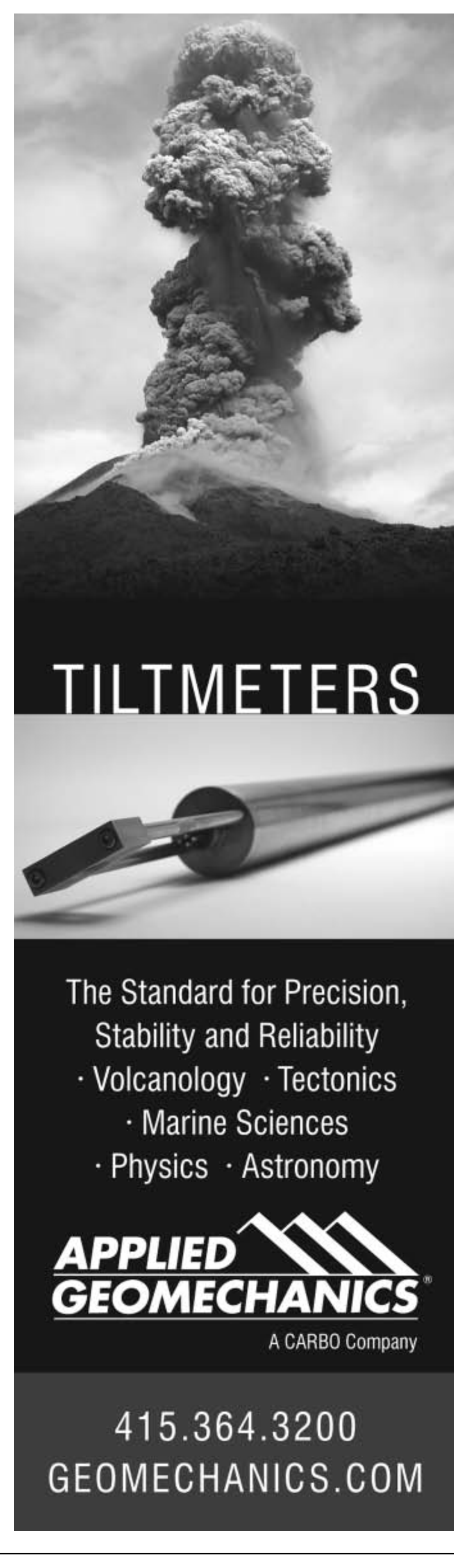
Benoît Mandelbrot, 85, 14 October 2010, Fellow, Nonlinear Geophysics, 1986

LETTERS

On the Correct Use of Statistical Tests

Comment on "Lies, Damned Lies, and Statistics (in Geology)"

Taking the distribution of global seismicity over weekdays as an illustration, Pieter Vermeesch (*Eos, 90*(47), 443, doi:10:1029/2009EO470004, 2009) in his Forum presented an argument in which a standard chi-square test is found to be so sensitively dependent on the sample size that probabilities of earthquake occurrence from these tests are uninterpretable. He suggests that statistical tests used in the geosciences to "make deductions more 'objective'" are at best useless, if not misleading.



In complete contradiction, we affirm that statistical tests, if they are used properly, are always informative. Vermeesch's error is to assume that it is possible to reduce in the chi-square test simultaneously both the number of earthquakes in each weekday and the sample size by 10. Instead, Vermeesch should have taken 10% of the original data set and then again grouped it into 7 days. Without doing this, it was inevitable that Vermeesch reached his erroneous conclusion.

Under the conditions that the sample is large enough, that the observations are independent and identically distributed, and that the zero hypothesis holds true, the p value should not depend essentially on sample size, as long as there are at least 10 observations per bin. The above mentioned change of the p value with sample size should thus signal the existence of some violation of the conditions for the chi-square test to be valid and not that statistics lie.

There are many possible causes for such violation, including aftershocks and catalog incompleteness. By removing aftershocks using a standard declustering method and using a more complete catalog with events of magnitude greater than 5.0, we obtain a p value of 0.46 for any given earthquake to fall on any day of the week. This large p value indicates that there is no preferential day that earthquakes occur. We can thus affirm that the main earthquake shocks with $M \geq 5.0$ are distributed uniformly over the seven weekdays, as expected from seismological intuition.

When properly used and interpreted, statistical tests always reveal useful information. Ridiculously small p values as found by Vermeesch should induce testers to question one by one the assumptions that underpin the statistical test used. Mathematics is not wrong; only its incorrect interpretation may lead to confusion and paradoxes.

See also the online supplement to this *Eos* issue (http://www.agu.org/eos_elec/).

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Careful Construction of Hypothesis Tests

Comment on "Lies, Damned Lies, and Statistics (in Geology)"

In his Forum, P. Vermeesch (*Eos, 90*(47), 443, doi:10.1029/2009EO470004, 2009) applied Pearson's chi-square test to a large catalog of earthquakes to test the hypothesis that earthquakes are uniformly distributed across day of week (the formal null hypothesis that an earthquake has equal probability of occurring on any day). In his analysis, this hypothesis is rejected, and he proposes that the statistical test implies that earthquakes are correlated with day of the week (with specifically high seismicity on Sunday), and therefore strong dependence of p values on sample size makes them uninterpretable.

It is a well-known property of classical hypothesis tests that the power of a statistical test is a function of the degrees of freedom, so that a test with large degrees of freedom will always have the resolution to reject the null. Consideration for practical as well as statistical significance is essential. Selecting bins so that the chi-square test fails to reject the null hypothesis is essentially formulating a test to agree with a foregone conclusion. To the point, this data set does not exhibit uniform seismicity across time, and the statistical test is summarizing the data correctly. With proper attention to the application setting, and formulation of the null and alternative hypotheses, summarizing with p values is technically sound.

It is the rejection of this null that causes inferential problems. There is no scientific basis for the claim that earthquake occurrence is correlated with day of week, and yet rejection of the null forces this as a possible conclusion.

We acquired the same data set used by Vermeesch, ordered the origins by epoch time, and noticed a large kink and change in slope of the empirical cumulative distribution function occurring at the time of the magnitude 9.1 great Sumatra earthquake of 26 December 2004, which, interestingly, occurred early on a Sunday at 0058:53 Greenwich mean time (GMT). The nonuniformity appears to be contamination of the earthquake catalog by aftershocks from a large earthquake (or earthquakes). The statistical tests (Pearson's chi-square and Kolmogorov-Smirnov) we applied gave the same conclusion as the Vermeesch analysis. A more plausible interpretation is that seismicity is uniform across time and that the great Sumatra earthquake introduced an outlier, much like the 100-year flood in the midst of a seemingly stable river flow pattern (see more interpretation in the online supplement to this *Eos* issue (http://www.agu.org/eos_elec/)). The statistical tests are clearly doing their job, and careful p-value analysis used in hypothesis testing is not necessarily uninterpretable, as suggested by Vermeesch. This exercise points out the importance of exploratory data analysis and careful formulation of a hypothesis test.

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A Closer Look at Data Independence

Comment on "Lies, Damned Lies, and Statistics (in Geology)"

In his Forum (*Eos, 90*(47), 443, doi:10.1029/2009EO470004, 2009), P. Vermeesch suggests that statistical tests are not fit to interpret long data records. He asserts that for large enough data sets any true null hypothesis will always be rejected. This is certainly not the case! Here we revisit this author's example of weekly distribution of earthquakes and show that statistical results support the commonsense expectation that seismic activity does not depend on weekday (see the online supplement to this *Eos* issue for details (http://www.agu.org/eos_elec/)).

To test if earthquakes are uniformly distributed over days of the week, we formed the series of daily earthquake occurrences and randomly shuffled its members to compute synthetic histograms of cumulative earthquake occurrences tallied by day of the week. We found that the resulting 95% confidence interval of earthquake tallies (15,897–18,076) contains the observed range of earthquakes, which had, when accumulated over the 10 years of data, a minimum of 16,349 occurrences on Friday and a maximum of 17,752 occurrences on Sunday. Hence, our test fails to reject the null hypothesis of uniform earthquake distribution throughout the week.

Why does the above test produce results different from those of the chi-square testing by Vermeesch? We argue that the effective number of independent observations (n^*) is less than the total number of earthquakes (n = 118,414). Vermeesch implicitly assumed that n^* equals n. However, closer inspection of the earthquakes used in Vermeesch's analysis shows that they exhibit periods of clustering that correspond to nonindependent aftershock sequences of strong earthquakes superimposed on the background of normal seismic activity. Thus, finding n^* meant statistically accounting for the fact that some of the earthquakes were linked and effectively eliminating them from the pool of events being analyzed. Such analysis revealed that only 10% of the events used by Vermeesch were actually independent ($n^* = n/10$; see the online supplement for more details on how we found n^*). Vermeesch's chi-square test that uses this new n^* value supports the notion that earthquakes do not depend on day of the week.

Similar results were obtained when we counted cumulative earthquake occurrences during each hour of the day instead of each day of the week and asked if earthquakes preferentially favored a certain time of day. They do not, as can be shown, for example, via chi-square testing using our estimated n^*, because n^* should not depend on the way the data are binned.

In summary, while the large databases permit identifying small-magnitude phenomena, care should be taken to ensure that the assumptions underlying statistical tests, such as data independence, are satisfied. Failing to do so may result in false rejection of null hypotheses.

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Misapplication of a Statistical Test

Comment on "Lies, Damned Lies, and Statistics (in Geology)"

In his Forum, P. Vermeesch (*Eos, 90*(47), 443, doi:10.1029/2009EO470004, 2009) argues that "the strong dependence of p values on sample size makes them uninterpretable" with an example where p values in a hypothesis test using Pearson's chi-square statistic differed by a factor of 10^{16} when the sample size decreased tenfold. The data were a sequence of magnitude 4 or larger earthquake events (N = 118,415) spanning 3654 days [*U.S. Geological Survey,* 2010].

There are two problems with the analysis. First, Vermeesch applied the chi-square test to data with statistical properties that are inconsistent with those assumed in the derivation of the chi-square test. Second, he made an assumption that, using a straightforward calculation, can be shown to be inconsistent with the data. I address here only problems related to the application of statistics without reference to any additional physical processes that may also need to be addressed before statistical analysis is performed (e.g., the physics of how aftershocks are related to main earthquakes).

First, Pearson's chi-square test applies to an experiment in which n independent measurements were made and each measurement falls into one of k categories. An analogous experiment would be n rolls of a seven-sided die, with each side labeled with a day of the week. The probability of two sequential rolls having identical labels is 14%. In the earthquake event list, two events in a row with identical day-of-week labels occur with probability 97%, which is not consistent with the independence assumption. As shown in the online supplement to this *Eos* issue (http://www.agu.org/eos_elec/), such a lack of independence may or may not result in a chi-square test rejecting the hypothesis of a uniform distribution on a histogram that was actually created by draws from a uniform histogram. The result depends on whether or not the events in question give a histogram with amplitudes that are Poisson-distributed, and nonindependent data do not necessarily create a histogram with Poisson-distributed amplitudes.

Second, Vermeesch assumed that if 10 times fewer measurements were used, chi-square would change from 93 to 9.3 when arguing that p values depend on sample size. This assumption is inconsistent with the data. In the case of the earthquake data, each day of the week occurred 522 times in the span of time selected. A new histogram with 10 times fewer data can be created by sampling with replacement only 52 of the available 522 days for each day of the week. For 1000 histograms created this way, chi-square is 70 ± 45 and not 9.3 as assumed.

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Lies or Misuse?

Comment on "Lies, Damned Lies, and Statistics (in Geology)"

To demonstrate a concern in geological interpretation after statistical hypothesis testing, writing that "geological hypotheses are never 'true'—they will always be rejected if lots of data are available," P. Vermeesch (*Eos, 90*(47), 443, doi:10.1029/2009EO470004, 2009) considers a null hypothesis H_0 of earthquake occurrences not depending on the day of the week. He found that his testing result rejects H_0, and he argues that the hypothesis testing does not reveal any geological significance. We argue that his conclusion basically demonstrates a Type I statistical error, where the null hypothesis is rejected despite being true.

Because the use of hypothesis testing crucially relies on three criteria—the correct null hypothesis, a plausible probability distribution, and an appropriate testing statistic—one will easily obtain an incorrect interpretation of statistical significance if one of these criteria is not met. Vermeesch's argument does not exhaustively address whether the last two criteria are met and is insufficient to claim that statistically the hypothesis should be rejected.

When the null hypothesis is treated as having a normal, instead of a uniform, probability distribution of occurrence, the chi-square test shows the same as that obtained by Vermeesch, where H_0 is rejected. Yet our analyses on both the raw data and subsets with a tenth of the original size randomly sampled from the raw data show a consistent H_0 rejection. This result disagrees with

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that of Vermeesch, who argues that sample size influences statistical results, which if true should hold for any distribution. This result also suggests that using uniform distribution for the null hypothesis may not reveal truth.

Furthermore, besides the chi-square test, a two-sample Kolmogorov-Smirnov (KS) test (see F. J. Massey, *J. Am. Stat. Assoc.*, *46*(253), 68–78, 1951) is also considered to see whether the probability distribution of one data set can be said with confidence to match another, information that helps to show that they describe the same phenomena. The KS test shows that the raw data (or the subsets of Vermeesch's earthquake data) and a normal probability distribution are almost the same, indicating that one cannot reject H_0. Even when a uniform probability distribution is used, the KS test still cannot reject H_0. The hypothesis of earthquake occurrences not depending on the day of the week is thus statistically significantly accepted by the KS test.

We thus suggest that users must pay considerable attention to determine the geological significance of the "uniformity" or "null hypothesis." One must be cautious with the application of hypothesis testing before confidently drawing conclusions after analysis.

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Statistical Significance Does Not Equal Geological Significance

Reply to Comments on "Lies, Damned Lies, and Statistics (in Geology)"

In my *Eos* Forum of 24 November 2009 (*90*(47), 443), I used the chi-square test to reject the null hypothesis that earthquakes occur independent of the weekday to make the point that statistical significance should not be confused with geological significance. Of the five comments on my article, only the one by *Sornette and Pisarenko* [2011] disputes this conclusion, while the remaining comments take issue with certain aspects of the geophysical case study. In this reply I will address all of these points, after providing some necessary further background about statistical tests.

Two types of error can result from a hypothesis test. A Type I error occurs when a true null hypothesis is erroneously rejected by chance. A Type II error occurs when a false null hypothesis is erroneously accepted by chance. By definition, the p value is the probability, under the null hypothesis, of obtaining a test statistic at least as extreme as the one observed. In other words, the smaller the p value, the lower the probability that a Type I error has been made. In light of the exceedingly small p value of the earthquake data set, *Tseng and Chen*'s [2011] assertion that a Type I error has been committed is clearly wrong. How about Type II errors?

If β is the probability of a Type II error, then the "power" of a statistical test is given by $1 - \beta$. It is well known that the power of a test increases with sample size n [*Cohen,* 1992]. Given the extremely large sample size of the earthquake data set (n = 118,415), the chance of a Type II error is also vanishingly small. The concept of statistical power lies at the heart of the problem at hand, as acknowledged in the comment by *Taylor and Anderson* [2011]. For example, the Kolmogorov-Smirnov test used by Tseng and Chen fails to reject the null hypothesis because it has very low power in this context.

The outcome of a statistical test depends on three parameters: the significance criterion (α, typically taken as 0.05), the sample size (n), and the so-called "effect size" (w). The key point in the present discussion is that whereas the absolute value of the effect size (for example, the height difference between two people) is scientifically interesting, the question of whether it is "significantly" different from zero is not only irrelevant but also can actually cause harm [*Ziliak and McCloskey,* 2008]. For a multinomial distribution (a.k.a. a histogram), the relationship between α, n, and w is well known and can be calculated analytically (for details, see the online supplement to this *Eos* issue (http://www.agu.org/eos_elec/)). Some key values for the earthquake problem are given in Table 1 and strongly contradict the claim by Sornette and Pisarenko that the p value should not depend on sample size.

The comments by *Kravtsov and Saunders* [2011], *Taylor and Anderson* [2011], and *Weigel* [2011] attribute the nonuniformness of the weekly earthquake distribution to the occurrence of aftershocks. I would like to remark that serial dependence and clustering of observations are not problematic, per se, unless they act on time scales that are shorter than the time span of the histogram, which is indeed the case for the weekly earthquake distribution. Sornette and Pisarenko remove the aftershock clusters by applying a number of progressively more restrictive "filters" to the data. Not surprisingly, they eventually manage to produce a data set that passes the chi-square test (p = 0.46). Not only is this a classical case of circular reasoning, but also the fact that the filtered data set contains only 5636 earthquakes (n/21) is an excellent illustration of the point my paper was trying to make. Using an effect size of w = 0.02726 (Table 1) and a significance level of α = 0.05, the power of the chi-square test applied to Sornette and Pisarenko's data set is only 0.26 (see the online supplement). In other words, they run a 74% chance of incurring a Type II error. In contrast, $\beta = 3 \times 10^{-10}$ for the full data set.

Table 1. Power Calculation of a Multinomial Distribution (Seven Bins, n = 118,415)[a]

Sample Size	Expected Chi-Squared Value	Expected p Value
n	94	4.5×10^{-18}
n/2	50	4.7×10^{-9}
n/4	28	9.4×10^{-5}
n/8	17	9.3×10^{-3}
n/13	13	0.05
n/20	10	0.11

[a]The expected chi-squared values are based on a noncentral chi-square distribution using a very small effect size of 0.02726 [*Cohen,* 1992]. See the online supplement to this *Eos* issue for details.

Weigel and Sornette and Pisarenko correctly pointed out that reducing the sample size by a factor of 10 does not result in an equivalent reduction of the chi-squared value. Table 1 shows that to have the false null hypothesis accepted, it does not suffice to divide the sample size by 10; it must be divided by 13. The reader will agree that this does not "significantly" change the conclusion of my paper, which has been eloquently formulated by the famous statistician John Tukey: "It is foolish to ask 'are the effects of A and B different?' They are always different—for some decimal place" [*Tukey,* 1991, p. 100].

See also the online supplement to this *Eos* issue (http://www.agu.org/eos_elec/).

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MEETINGS

Hydroecological Responses to Climate Change in Northern Catchments

Northern Watershed Ecosystem Response to Climate Change (North-Watch) Workshop III: Hydroecological Responses to Climate Change in Northern Catchments; Aviemore, United Kingdom, 29 August to 2 September 2010

North-Watch is an interdisciplinary intersite comparison project funded by the Leverhulme Trust, United Kingdom, and run by the Northern Rivers Institute, University of Aberdeen, Aberdeen, United Kingdom. The overall aim of the North-Watch project is to facilitate an intercatchment comparison study of high-latitude catchments that will yield a comprehensive, interdisciplinary, and regional understanding of the recent effects of climatic change and provide a stronger scientific basis for predicting what further changes are likely. Examining a range of sites across a climatic transect in the northern zone will give a much stronger regional perspective on the responses to climatic change than individual studies alone. The project is analyzing long-term data from experimental catchments including sensitive boreal, sub-Arctic, and sub-Alpine environments ranging from the Yukon and northern Sweden to the Scottish Cairngorms to assess the integrated physical, chemical, and biological response to climatic change.

Recently, North-Watch held its third international workshop, which brought together 15 specialists from Scotland, Sweden, Canada, United States, Switzerland, and Germany representing universities and government institutions. The major goal of this workshop was for participants to expose one other to different ways of looking at linkages between hydrology and the structural-functional relationships of terrestrial and aquatic ecosystems in northern catchments in the context of a changing climate. Workshop participants aimed to understand the complex feedback between catchment hydrological response to climatic forcing and the complex feedback between landscape and ecosystem response. A major research challenge is to understand the structural-functional relationships of different ecohydrological units within landscapes and the sensitivity of these units to climate or environmental changes.

Although there has been considerable cross-fertilization of ideas between hydrology and ecology over the past 2 decades, many of the potential synergies remain undeveloped. At the simplest level, ecological classification schemes often do not map readily onto hydrological classifications despite similar drivers (e.g., precipitation and temperatures). Workshop participants suggested that a likely fruitful direction will be in the search for common functional metrics (e.g., patch size, distance weighting of the position of critical land cover types within the catchment) rather than structurally based metrics (e.g., percent cover of a landscape characteristic) for ecological (whether terrestrial or aquatic) and hydrological systems. Not only will this help identify direct synchronicity between hydrology and ecology, but given the complex interactions of biotic and abiotic controls on ecosystem processes, it will also help identify residual hydrological influences such as those of high-magnitude, low-frequency extreme events. Workshop participants benefited from key ecological concepts that might be useful for hydrological investigations such as intermediate disturbance hypothesis, shifting baseline, or biotic cascades and feedbacks.

The next North-Watch workshop will be held in Hubbard Brook Experimental Forest, New Hampshire, in April 2011, and will be titled "Simple Models for Complex Problems: Using Empirical Data and Models in a Learning Framework for Prediction in Northern Catchments." Information on North-Watch and its most recent workshops can be found at http://www.abdn.ac.uk/northwatch/.

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Studying Silicate-Ice Bodies in the Solar System

Evolution of Small Silicate-Ice Bodies in the Solar System; Winthrop, Washington, 6–8 August 2010

Interest is growing in a class of small bodies in the solar system, some of which are believed to be the building blocks of the terrestrial planets. These include Ceres, Vesta, Pallas, the icy satellites, and some solid objects farther out in the solar system. Many of these objects appear, from their bulk density and shape, to be composed of a mixture of water and silicates, with short- and long-lived radioisotopes as energy sources. These are the ingredients for dynamic thermal evolution, including differentiation and mineral and carbon chemistry, and the potential for internal liquid water layers even today.

Evidence for this comes from at least one family of asteroids, the Themis group, which may be pieces of a differentiated water- and organic-rich protoplanet. The Themis family is being studied to reveal a profile of its parent body. Also, the NASA Dawn spacecraft (C. T. Russell et al., *Planet. Space Sci., 52*(5-6), 465–489, 2004) is on its way to orbit Vesta in 2011 and Ceres in 2015. These objects and the Dawn mission stimulated a workshop series, initiated in 2006, to assess the evolutionary history of these objects, with the fourth workshop held at the Bear Fight Institute in Washington State. The major physical and chemical processes involved were covered at the workshop. The workshop focused on the development of a composition model for Ceres's surface to help plan the Dawn observations. The approach built on recent publications of thermodynamic models for Ceres (T. B. McCord and C. Sotin, *J. Geophys. Res., 110,* E05009, doi:10.1029/2004JE002244, 2005; J. C. Castillo-Rogez and T. B. McCord, *Icarus, 205*(2), 443–459, 2010) and involved representatives from a variety of fields: cosmochemistry, geophysics, geology, remote sensing, and material properties.

One research area identified at the workshop is how chemistry drives thermal evolution, for example, by affecting the thermophysical properties of the accreted icy and rocky materials, and how the geochemical environments change with evolution. Relevant processes include mineralization and heating, resulting from the interaction of liquid water and silicate grains following differentiation, and the long-term preservation of liquid layers. Heat from long-lived radioisotopes eventually drives inner core dehydration, which affects the entire object, especially through energy exchanges. Late-stage hydrothermal circulation as the core is cooling may further promote hydrogeochemistry. Carbon and perhaps ammonia, if found to be present at Ceres, would lead to more possibilities for interesting chemistry, perhaps as a base for biology. Participants agreed that important observations for Dawn to make include the surface compositions and signatures of endogenic activity. These observations can provide information about Ceres's present interior.

There is growing observational and theoretical evidence confirming the thermal or chemical activity within these silicate-ice objects, and this class of objects in the solar system is gaining recognition for its habitability potential. Thus, the Dawn mission, NASA's New Horizons mission to Pluto, and subsequent missions have the potential for major discoveries.

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